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Understanding the farmers' choices and adoption of adaptation strategies, and plans to climate change impact in Africa: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

The study evaluates the farmers' choices and adoption of adaptation measures and plans by smallholder farmers to reduce the effects of climate change on their farming activities. We conducted a systematic review using the Preferred Reporting Items for Systematic Reviews and meta-Analyses (PRISMA) method. We found 66 associated studies to understand farmers' adaptation measures to climate change impacts in Africa. The paper summarizes four categories, including i) crop varieties and management; ii) water and soil management; iii) financial schemes, migration, and culture; and finally, iv) agriculture and weather services. The findings revealed that majority of studies identified crop diversification (51.5%), planting drought-tolerant varieties (45%), changing planting dates (42%), and planting early maturing crops (22%) as dominant strategies. These adaptation strategies are a welcome development and may be beneficial for responding to the impacts of climate change. However, they might not be effective during times of more extreme climate changes in the coming decades. Hence, more transformative changes, such as building more infrastructures for irrigation, promoting crop insurance, using improved varieties, and increasing opportunities for livelihood diversification, should be considered in addition to the existing adaptation strategies and potentially contributes towards SDG 1 (No Poverty) and 2 (Zero Hunger).

Introduction

Climate change is a global phenomenon that threatens farmers' livelihood and agricultural farming, particularly in semi-arid areas in Africa (Niang et al., 2014; Mugambiwa & Tirivangasi, 2017; Roy et al., 2018). Continued warming will impact sectors essential for Africa's economic development, including the agricultural industry (Magesa & Pauline, 2018). Decadal analysis of temperature data across many parts of Africa strongly indicates an increased warming trend of 0.5 °C or more over the last 50–100 years (Niang et al., 2014). Minimum temperature warming is more rapid than maximum temperature warming (Funk et al., 2012; Nicholson et al., 2013). Besides, observations have shown that annual precipitation has decreased in the eastern and western Sahelian regions (Niang et al., 2014). Droughts are likely to increase and intensify in the 21st century due to reduced precipitation and increased evapotranspiration in Eastern and Southern Africa, whereas heavy precipitation events are likely to rise in East Africa (IPCC, 2012; Niang et al., 2014). In addition to the relatively low rainfall levels in many African countries, the effects of climate change on precipitation patterns, temperature, weed, pest, and disease pressure are likely to make agriculture more challenging (Boko et al., 2007; Niang et al., 2014). Moreover, the continent faces a food crisis due to droughts, crop pests (i.e., desert locusts), and civil conflicts (Kotir, 2011; Mugambiwa & Tirivangasi, 2017). The fact that about 64 % of the world's poorest people lived in sub-Saharan Africa in 2020; and approximately 427 million people in Africa are still living in extreme poverty establishes Sustainable Development Goals 1 (No poverty) and 2 (Zero hunger) as essential goals in the region (Kharas & Dooley, 2021).

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As agriculture is the primary economic activity in terms of employment on the continent and is considered necessary in alleviating poverty, ending hunger, and achieving food security, makes even more challenging to attain SDG 1 and SDG 2 (Mugambiwa & Tirivangasi, 2017). The agriculture sector accounts for over 25 % of gross domestic product and 70 % of the labor force in Africa (Pereira, 2017; Fadina & Barjolle, 2018). Despite the importance of agriculture, the region's agricultural systems, particularly in sub-Saharan Africa, are 98 % rainfed with a few technological inputs. Only 5 % of the cultivated area in Africa is irrigated compared with 14 % in Latin America and 37 % in Asia (Ringer et al., 2010). Additionally, most African farmers practice small-scale or subsistence agriculture and have limited access to infrastructure, financial resources, and information (Deressa et al., 2010; Pereira, 2017). Various studies (Boko et al., 2007; Ringer et al., 2010; Komba & Muchapondwa, 2015; Pereira, 2017) indicate that Africa's agricultural systems will be hit hardest by climate change. Ringer et al. (2010) further added that the rural populations in the region, who rely on agriculture as their primary livelihood activity, would be most affected by the direct exposure of agriculture to climate change.

Given this situation, adaptation has become an important option necessary to reduce the current observed and projected impacts of climate change (Boko et al., 2007; Komba & Muchapondwa, 2015; Wondimagegn & Lemma, 2016). Adaptation is the adjustment of natural or human systems in response to expected or actual climatic stimuli or their effects to moderate harm and exploit beneficial opportunities (Boko et al., 2007). There has been growing concern about whether climate change adaptation efforts are mainly positive in achieving SDGs (Denton et al., 2014). Not every adaptation measure to climate change is a good one. Therefore, more researchers are looking for sustainable adaptation measures and strategies that reduce vulnerability to climate change and contribute to social equality and environmental integrity (Brown, 2011; Bhatasara & Nyamwanza, 2018).

In some cases, what seems to be successful adaptation measures to climate change impacts may undermine sustainable development's economic, social, and environmental objectives (Eriksen et al., 2011). According to (Dube et al., 2018a; Dube et al., 2018b) study reveals that the stream bank crop cultivation villagers used in the Gwanda District, Zimbabwe, as an essential adaptation strategy, contributed to soil erosion, denudation and siltation of rivers and the local Mnyabezi dam. Siltation has negatively affected the dam's effectiveness and continuity, leading to a water shortage for irrigation and livestock production in the village. Extensive stream bank crop cultivation leads to deforestation due to the removal of vegetation along the rivers for crop production; the pattern exposes the soil to denudation forces such as wind and water, which causes soil erosion (Dube et al., 2018a; Dube et al., 2018b). Vanderwel and Jedrych (2005) added that growing crops too close to a water body increases the risk of sediments and reduces bank stability. Also, Eriksen & O'Brien (2007) showed that even though the high vulnerability of poor people to climate change justifies the use of adaptation interventions, not every adaptation measure reduces the exposure of the poor or contributes to poverty reduction. This is because undertaken adaptation strategies may minimize the risk in the short term while appearing to increase vulnerability in the long time (Dube et al., 2018a; Dube et al., 2018b). A study by (Bola et al., 2014) showed that adaptation strategies used by households in Mbire District, Zimbabwe were inefficient in reducing impacts associated with floods and droughts. Besides, (Mtekwa, 2009) revealed that strategies such as gold panning that farmers in Zvishavane District, Zimbabwe are illegal and environmentally degrading. In due regard, it is becoming essential to understand the efficiency of farmers' adaptation strategies and policy implications on reducing climate change impacts (Bhatasara & Nyamwanza, 2018; Williams et al., 2021). A thorough analysis of the positive and negative interactions of potential adaptation strategies is very important for climate change adaptation planning (Nilsson et al., 2016).

Although there are abundant studies on farmers' adaptation strategies to climate change impacts in Africa, very few studies, have systematically reviewed how farmers' adaptation strategies in the region effectively reduce food insecurity and poverty. Most of the previous reviews (e.g., Somorin, 2010) present the vulnerability and adaptation strategies of forest-dependent rural communities to climate change impacts, whereas a study by Mohammed et al. (2014) shows the farmers' adaptation strategies to climate change on the farm level localities. Conversely, Akinnagbe & Irohibe's (2014) review presents agricultural adaptation strategies to climate change in Africa, while Sani and Chalchisa (2016) present adaptation strategies used by smallholder farmers to climate change impacts in sub-Saharan Africa. Further, Jellason et al., 2022 highlighted the importance of the integration of local and scientific knowledge is beneficial for smallholder farmers in sub-Saharan Africa. It enables significant adaptation measures to climate change in the region. Despite the contributions made by these reviews toward agricultural adaptation strategies used by farmers in various African countries, little is known about the continued effectiveness of these adaptation strategies at higher global warming levels (Williams et al., 2021; Trisos et al., 2022). The current and future impacts of climate change highlight the need for information on the efficiency of farmers' adaptation measures, and proper plans to climate change in Africa to enable climate change adaptation planning (Magesa & Pauline, 2018; Williams et al., 2021). Additionally, the fifth IPCC Assessment Report calls for more knowledge and research on responding sustainably to climate change impacts and challenges associated with adaptation projects to sustainable development (Denton et al., 2014).

Therefore, to fulfil this research gap, the paper predominantly targets the farmers' choices and adaptation strategies to climate change in Africa using a systematic review approach. A total of sixty-six studies were systematically selected, preferably plant-based agriculture studies. To address the goal of this paper, we anticipate responding to the following research questions. What are African farmers' effective plans and adaptation strategies to cope with climate change? How do these adaptation strategies potentially contribute towards SDG 1 (no poverty) and 2 (zero hunger) in the region?

The three key objectives guided the study and response to the above questions are; (i) to review adaptation strategies used by smallholder farmers to reduce the effects of climate change on their agricultural activities in Africa; (ii) to understand the efficiency of farmers' adaptation measures, and plans to climate change impacts in Africa; and finally (iii) to investigate the positive and negative interactions among adaptation measures and SDGs indicators of No Poverty and Zero Hunger.

2. Methodology

2.1. Selection of literature and search strategy

The study employed the PRISMA (Preferred Reporting Items for Systematic Reviews and meta-Analyses) guidelines to systematically review peer-reviewed literature. The PRISMA method is often used in the environmental field. We opted for this approach because it clearly; (i) identifies inclusion and exclusion criteria and (ii) defines research questions that permit systematic research (Moher et al., 2009; Shaffril et al., 2018).

The peer-reviewed articles focusing on farmers' adaptation strategies to climate change impacts in Africa were collected from the two world-leading and competing citation journal databases, Scopus and Web of Science (WoS), for ten years from 2001 to 2021. Several studies have compared these two databases (Zhu and Liu, 2020). We used different search keywords to test which ones could provide a significant number of articles to conclude our literature search. The key search terms (see Table 1) included the following: "adaptation" AND "strategies" AND "farmers" AND "agriculture" AND "SDGs" AND "Africa," which yielded only three papers: "adaptation strategies" AND "farmers" AND "agriculture" AND "Africa" generating 85 papers; and "agriculture" AND "sustainability" AND "adaptation" AND "strategies" AND "Africa" which

Table 1
Search strings used.

Key search terms used in Scopus	No. of articles	Key search terms used in WoS	No. of articles
"adaptation strategies" AND farmers AND agriculture AND Africa	85	'adaptation' AND 'agriculture' AND 'sustainability' AND 'short-term.'	19
adaptation AND strategies AND farmers AND agriculture AND SDGs AND Africa	3	'adaptation strategies' 'farmers' 'agriculture'	221
"agriculture" AND "sustainability" AND "adaptation" AND "strategies" AND "Africa."	33		
"adaptation" AND "strategies" AND "farmers" AND "agriculture" AND "Africa."	166		

returned 33 articles. Based on these results, we decided to use "adaptation" AND "strategies" AND "farmers" AND "agriculture" AND "Africa" for Scopus as an alternative search string that provided us with a significant number of articles. We used 'adaptation strategies' 'farmers' 'agriculture' AND 'Africa' (Fig. 1 & Table 1). The search resulted in 166 articles in Scopus and 221 articles in WoS. Then, 73 duplicates were identified and removed, resulting in 314 articles. These articles were then subjected to a screening process (see Table 2).

The first screening was based on the titles and abstracts of the searched papers. Out of 314 articles eligible to be reviewed at this stage, 173 articles were selected, and 141 were removed as some did not focus on plant-based agriculture, farmers' adaptation strategies to the impacts of climate change and variabilities, or they did not focus on African territories. The second screening was based on complete text analysis. All 173 articles were read during this stage to determine whether they discussed farmers' adaptation strategies to climate change impacts and whether they focused on African territories. Moreover, these articles were carefully analyzed to determine the positive and negative interactions between farmers' adaptation strategies and "No Poverty and Zero Hunger" indicators. After careful examination, 107 articles were excluded as some did not focus on African countries, farmers' adaptation strategies to climate change, or plant-based agriculture. The last stage of the review resulted in a total of 66 articles selected for analysis.

In addition, a VOSviewer tool was used to analyze the co-occurrences of keywords used in the articles (Van Eck & Waltman, 2014; Rodriguez et al., 2016; Nazarian & Lee, 2021) (see https://www.vosviewer.com). Thirty-two articles from Scopus and 34 from the WoS were exported as CVS files and then imported as input into the VOSviewer package, and analyses were performed simultaneously. Then, the co-occurrence of keywords in the selected articles was determined with a minimum occurrence set of five to show clusters and links. Further, we used the SDG positive and negative interactions framework developed by Nilsson et al. (2016) to recognize the linkages between farmers' adaptation, selected indicators, and potential contribution toward SDG 1 (no poverty) and 2 (zero hunger; see Table 4). Whereas the positive interactions are considered as those which provide and offer strategies that enhance the development of other sectors, e.g., poverty reduction, food security; increased income, and ensuring sustainable use of natural resources while increasing resilience to the current observed and projected impacts of climate change (McCollum et al., 2018). On the other side, negative interactions were considered strategies that may introduce unintended consequences, such as unsustainable use of natural resources, the possibility of increasing poverty, food insecurity, and vulnerability to climate change (Nilsson et al., 2016; McCollum et al., 2018).

3. Results

3.1. Year-wise progress of articles published

Our literature search found that the number of publications on farmers' adaptation strategies to climate change impacts in Africa increased from 2001 to 2020 (see Fig. 2). Further, the earliest publication on the topic was published in 2001. In addition, our literature

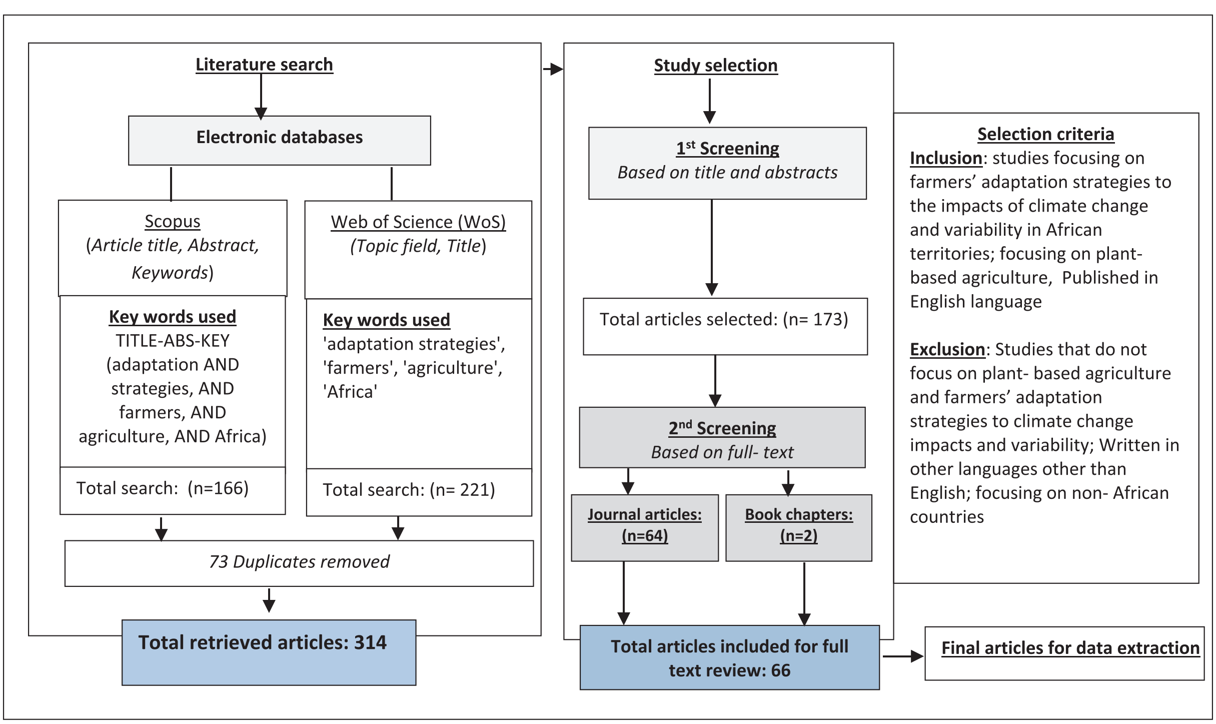

Fig. 1. Methodology flowchart; Modified from Escarcha et al. (2018).

Table 2
Distribution of types of methods and data used for identifying farmers and researchers' recommended strategies.

S. No.	Author Name	Country	Type of data observations (Note-1)	Farmers Implemented strategy (Note-2)	Researchers recommend strategy (Note-2)	Methods Adopted
1.	Thomas et al., 2007	South Africa	1,2,3	1,11,13,14	1,11,13,14	SOM analysis
2.	Bryan et al. (2009)	South Africa and Ethiopia	1, 2	1, 2, 7, 11, 13, 20		Binary response model
3.	Nindi and Mhando (2012)	Tanzania	1,2	1, 8, 15, 23		Content analysis
4.	Antwi-Agyei et al. (2014)	Ghana	1, 3	1, 2, 3, 20, 22, 23,	11, 21, 26	Content and descriptive analysis
5.	Harvey et al. (2014)	Madagascar	1,2,3	1, 20	11, 16, 17, 27,28,29	Spearman correlations
6.	Below et al., 2015	Tanzania	1,2	1,3,11, 12, 13,15, 17, 18, 19	26, 27, 29	Multiple linear regression analysis
7.	Fagariba et al., 2015	Ghana	2, 3	1, 2, 3, 15	11, 15, 22	logistic regression model
8.	Mavhura et al., 2015	Zimbabwe	1	1, 20	11	Content analysis
9	Traore et al. (2017)	Mali	4		3, 16, 17	APSIM model predictions
10	Elum et al. (2018)	South Africa	1		11, 24	The Ricardian model
11	Mupakati and Tanyanyiwa (2017)	Zimbabwe	1,2,3	1, 12, 20	1	Content analysis
12	Osei, 2017	Ghana	1, 2, 3	1, 3, 4, 12, 14, 20	29	Kendall's coefficient of concordance and Friedman's test
13	García de Jalón et al., 2018	Burkina Faso, Mali, Niger, Senegal, Ethiopia,Tanzania, Uganda	1	1, 12		Random intercept logit mode
14	Popoola et al., 2018	South Africa	1	1, 2, 7, 10, 12, 14		Principal component analysis (PCA)
15	Dube et al., 2018a; Dube et al., 2018b	Zimbabwe	1,2,3	1, 9, 10, 12,		Content analysis
16	Samuel and Sylvia, 2019a,b	South Africa	1, 2	1, 2, 20, 25		Principal component analysis (PCA)
17	Waldman et al., 2019	Kenya	1	1, 3, 12, 20		Linear regression model
18	Bailey et al., 2019	Eswatini	1, 2	1		Generalized linear model
19	Kogo et al., 2019	Kenya	4		1, 2, 3, 11, 20, 22, 29	Climate simulation models
20	Abid, et al., 2019	Malawi	1	1, 2, 5, 20	26, 28, 29	Probit model
21	Tarfa et al. (2019)	Nigeria	1	1, 5, 6, 11, 20, 22	4, 11, 20, 26, 29	Multivariate probit model
22	Olajire et al., 2019	Nigeria	1, 4	1, 2, 11, 12, 13, 14, 17	2, 11, 17	Crop simulation models
23	Frederick and Nielsen (2019)	Ghana	1, 2	1, 4, 8		Cross tabulation and content analysis
24	Darabant et al., 2020	Ethiopia	2	1, 2, 3, 4, 5, 7, 11, 13, 20, 22		The Standardized Precipitation Evapotranspiration Index (SPEI) and content analysis
25	Ngcamu and Chari, 2020	Nigeria, South Africa	5	1, 20		NVivo software (content analysis)
26	Alvar-Beltrán et al., 2020	Burkina Faso	1	1, 7, 15		Linear regression
27	Atube et al., 2021	Uganda	1	1, 4, 7, 20	29	Binary logistic regression
28	Muroyiwa et al., 2021	South Africa	1	1, 2, 20		Double hurdle model
29	Mburu et al., 2015	Kenya	1, 2	1, 2, 3, 12	29	Chi-square test and content analysis
30	Kassie et al. (2013)	Ethiopia	1, 2, 3	2, 20		Descriptive statistics
31	Talanow et al., 2021	South Africa	1	1, 2, 3, 16, 20		Content analysis
32	Ndhleve et al. 2017	South Africa	1	1, 3, 11		Yield gap analysis
33	Gbetibouo et al., 2010	South Africa	1	2, 11, 13, 14, 20	11, 22, 28, 29	Multinomial logit analysis
34	Bryan et al., 2013	Kenya	1, 2	2, 7, 15, 16, 20	11	Binary and multinomial choice models
35	Muita et al. (2015)	Kenya	1	2, 3, 20,		
36	McCord et al. (2015)	Kenya	1	2, 20		Regression analyses
37	Ado et al., 2020	Niger	1	2, 4, 7, 16, 20, 22, 30	4, 26, 28	Descriptive statistics and a regression model
38	Diallo et al., 2020	Mali	1	2, 3, 17	3, 17	The multinomial logit model
39	Baudoin et al., 2014	Benin	1, 2	2, 3, 23,		Content analysis
40	Daccache et al., 2015	Malawi	4	2, 12, 14,		CERES-Rice crop model
41	Mogomotsi et al., 2020	Botswana	1, 3	1, 2, 3		A probit regression model
42	Comoe et al. (2014)	Cote d'Ivoire	2	2, 3,20, 25		The framework analysis
43	Muthelo et al., 2019	South Africa	1	11, 13, 14, 24		The multinomial probit model
44	Mulinde et al. (2019)	Uganda	1	16, 22, 30	27, 28, 29	Principal Component and Multivariate Cluster Analyses
45	Quandt, 2020	Kenya	1	15	15	Thematic coding
46	Yegbemey, 2020	Benin	1	2, 12, 20,	29	A tri-variate Tobit regression model
47	Yegbemey et al., 2017	Benin	1	20, 23, 25		A tri-variate Tobit regression model
48	Mashizha, 2019	Zimbabwe	1	20, 22, 23	11	Regression analysis
49	Nuamah and Amungwa (2021)	Ghana	1	1, 2,4, 16, 20, 22, 23, 29	29	Binary logistic regression models
50	Roncoli et al. (2001)	Burkina Faso	1	20, 23	4, 22, 26, 28	Ethnographic research
51	Kotir (2011)	Sub-Saharan Africa	5	2, 7, 16, 20, 22	22, 26, 27, 28, 29	Literature review

(continued on next page)

Table 2 (*continued*)

S. No.	Author Name	Country	Type of data observations (Note-1)	Farmers Implemented strategy (Note-2)	Researchers recommend strategy (Note-2)	Methods Adopted
52	Thinda et al., 2020	South Africa	1	2, 3, 4, 7, 23, 24	4, 22, 24	Zero-inflated double hurdle model
53	Mertz et al., 2009	Senegal	1, 2, 3	20, 22, 23		
54	Gandure et al. (2013)	South Africa	1, 2	2, 12, 20	11	
55	Eludoyin et al., 2016	Nigeria	1	2, 3, 20, 22		Analysis of variance
56	Ali et al., 2020	Togo	1	2, 7	29	Regression analyses
57	Myeni and Moeletsi (2020)	South Africa	1, 2, 3	3,11, 12, 20	2, 3, 11, 12, 20	Frequency analysis and a binary logistic model
58	Ngure et al., 2020	Kenya	1, 2, 3	20, 23		Descriptive statistics and content analysis
59	Amfo et al., 2020	Ghana	1	20		Beta regression model
60	Williams et al., 2020	Ghana	1, 2, 3	11, 12, 13, 16		Equal weighting and
61	Kativhu et al., 2020	South Africa	1, 3	1, 11, 12	11	Descriptive statistics and principal component analysis
62	Makate et al., 2019	Malawi and Zimbabwe	1	1, 4, 5	1, 4, 29	Multinomial logistic regression
63	Amadou et al., 2018	Ghana	1		4, 11, 28, 29	Land Use Dynamic Simulator
64	Williams et al., 2019	Ghana	1, 2, 3	1, 2, 3, 4, 11, 17, 20, 22, 23, 24		Descriptive analysis and Weighted Average Index
65	West et al., 2008	Burkina Faso	1, 2, 3	2, 8, 20, 23		Descriptive and content analysis
66	Ndlovu et al. (2020)	Zimbabwe	1, 2, 3	3, 12, 23		Thematic analysis

Note-1: 1. Household Survey, 2. Focus Group Discussion, 3. Key Informant Interviews, 4. Field experiment, 5. Review paper.
Note-2: 1.Planting drought tolerant varieties; 2. Changing planting dates; 3. Planting early maturity crops; 4. Use of Improved varieties; 5. Planting disease resistant varieties; 6. Use of flood tolerant crop; 7. Planting trees; 8. Valley bottom cultivation; 9. Stream Bank Crop Cultivation; 10. Cultivating crops in wetland areas and near water sources; 11. Irrigation schemes; 12. Water harvesting dam, pond and trenches; 13. Pump irrigation from river; 14. Boreholes and streams; 15. Agroforestry; 16. Inorganic fertilizers; 17. Organic fertilizers; 18. Bucket irrigation from river; 19. Deep tillage; 20. Crop diversification; 21. Early warning systems; 22. Livelihood diversification; 23. Seasonal migration; 24. Insurance schemes; 25. Prayers; 26. Credit schemes; 27. Improving road infrastructure; 28. Access to market; 29. Extension services; and 30. Use of Pesticides.

search did not find papers between 2002 and 2006 on farmers' adaptation strategies to climate change impacts in Africa. The publications increased between 2007 and 2009, 2013 and 2015, and 2016 and 2020. Both 2019 and 2020 had the highest number of publications, with 2019 having 12 and 2020 having 16 publications (see Fig. 2).

Journals with the highest number of relevant publications were *Climate Change* with five papers (7.6 %), and *Environmental Management* with four papers (6 %) (see Appendix 2). Other journals, including the *Jamba: Journal of disaster risk studies; and Environment development and sustainability*, had three relevant papers. However, the remaining journals had one or two publications. Additionally, although most of the publications were journal articles (93.9 %), there were also some book chapters (3 %).

3.2. Country-wise distribution of articles published in Africa

Most relevant publications focused on sub-Saharan African countries (see Fig. 3). Based on the results of this systematic review, our literature search did not find papers from Northern African countries. About 94 % of the publications were country-specific, and the remaining 6 % focused on more than one country (regional coverage). South Africa was the

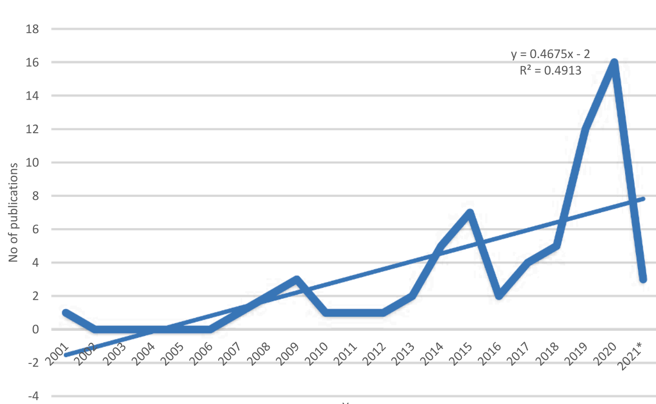

Fig. 2. Year-wise published papers on farmers' adaptation strategies. *Note: Until March, three articles were published in 2021.

most studied country level, with 15 publications (Fig. 3). The second most studied country was Ghana, with nine publications, followed by Kenya (eight) and Zimbabwe (six). Except for Tanzania, Ethiopia, Burkina Faso, Benin, and Nigeria, each had three publications; the remaining countries had either one or two. Based on publications focusing on more than one country, Malawi, Ghana, Tanzania, Kenya, and Ethiopia appeared the most (two times each). Other countries, such as Zimbabwe, South Africa, Burkina Faso, Uganda, and Mozambique, seemed once.

On the other hand, a co-occurrence map of keywords was generated to provide a visual representation of keywords used in the study, their co-occurrence, interlinkages across different disciplines, and the emerging themes (Fig. 4). The size of words and nodes in Fig. 4 represents the weights of the nodes (Liao et al., 2018). Hence, more significant observations and nodes indicate keywords frequently appearing in the literature sample. The distance between two nodes represents the strength of the relation between two nodes. A shorter distance reveals a more important link. A longer distance shows a weak connection among keywords, whereas the line between keywords indicates that they appear together (Van Eck & Waltman, 2014).

The keyword "climate change" had the highest frequency of 87 occurrences. Other keywords with high frequency include "agriculture" (53), "Africa" (39), and "sub-Saharan Africa" (33). Clusters indicated by the colour in the bibliographic network map (Fig. 4) represent a set of closely related keywords that are clustered together based on their co-occurrences and relatedness. Four significant clusters are formed in this analysis, indicating the considerable subtopics in farmers' adaptation to climate change in Africa. In the first cluster (red,) the dominant keywords such as "*crop production*, "*climate effect,*" and "*rainfed agriculture* indicate research on climate change impacts on crop production and agricultural policies. The second cluster (yellow) has keywords such as "*vulnerability,*" "*adaptation strategies,*" and "*perception,*" indicating research on vulnerability, farmers' perceptions, and adaptation strategies to climate change. The third cluster (green) is very closely connected to climate change, crops, and sub-Saharan Africa, indicating research concentrating and focusing on the impacts of climate change on crops in sub-Saharan Africa; whereas in the blue cluster, agriculture, droughts and Africa have more links which are closely connected. This

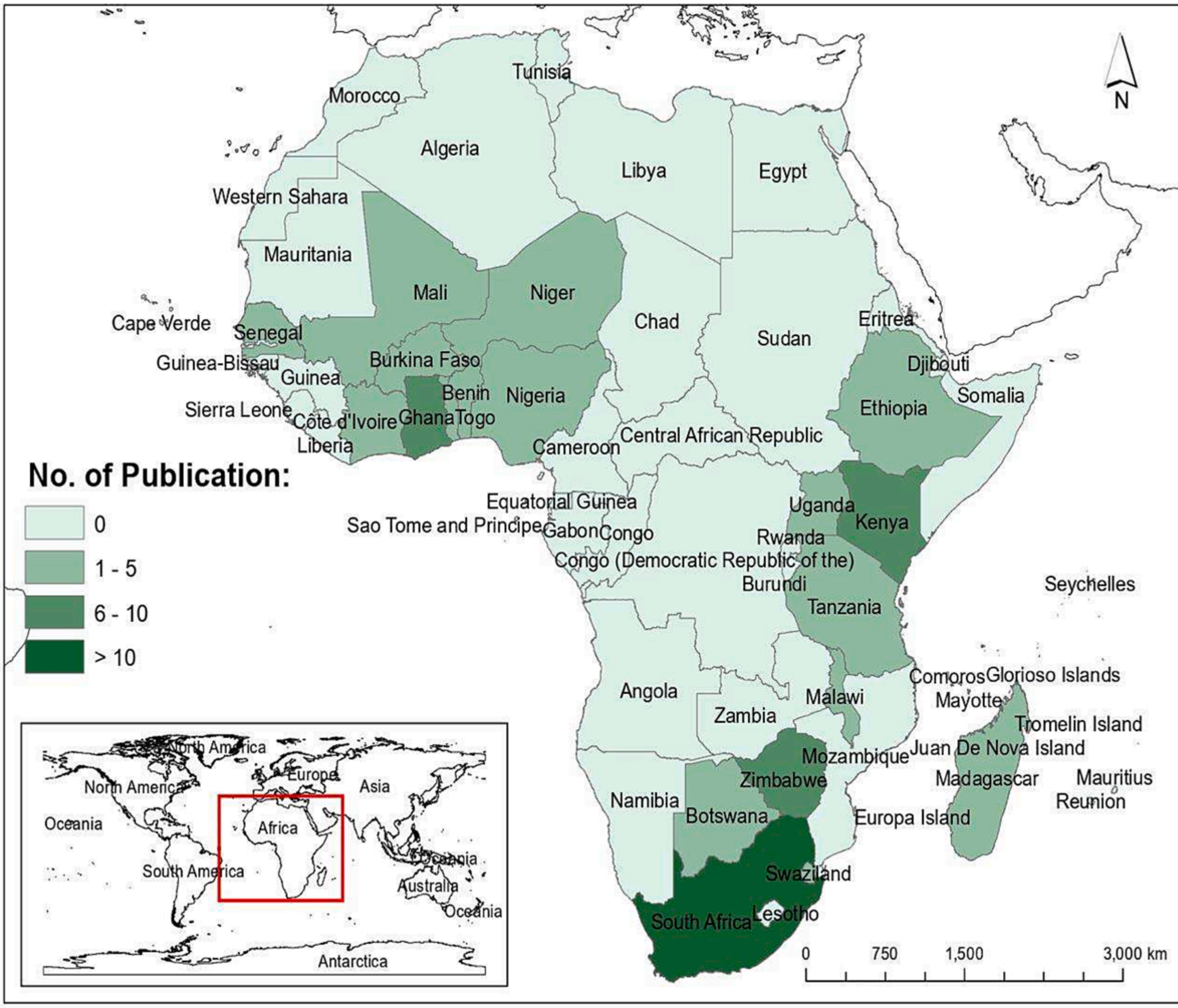

Fig. 3. African comprehensive publications on Farmers' Adaptation Strategies.

indicates research focusing on the impacts of droughts on agriculture in Africa.

3.3. Data collection instruments and methodologies used in studies focusing on farmers' adaptation strategies to climate change in Africa

A list of farmers' adaptation strategies to climate change in Africa is presented in Table 3 from the selected literature. Approximately 89 % of the studies employed household surveys, followed by Focus Group Discussions (FGD), 26 (39.3 %) studies. Other methodologies included key informant interviews in 17 (25.8 %) studies, field experiments in 4 (6 %) studies, and review papers in 2 (3 %) studies. The studies that used FGDs and household surveys accounted for 3 (8 %), whereas 19.7 % of studies adopted FGDs, household surveys, and key informant interviews. Nevertheless, some studies recorded more than one method to assess farmers' adaptation strategies to climate change in Africa. In addition, we categorized all the identified thirty disaggregate adaptation strategies under four aggregated principal adaptation measures (see Table 3).

3.4. Identification of principal adaptation strategies to climate variability and change in Africa

Crop diversification has been revealed as a key strategy adopted by farmers in 34 studies (51.5 %), followed by planting drought-resistant varieties 30 studies;45 %), changing planting dates (28 studies; 42 %), and planting early maturity crops (15 studies; 22.7 %) (Table 3). Out of 19 countries in the publications, crop diversification was practised in 14 countries. However, planting drought-resistant varieties was practised by farmers in 15 countries, whereas changing planting dates were used by farmers in 12 countries.

Some adaptation strategies were related to irrigation and water management practices. For example, 12 publications (18.1 %) indicated that most farmers used hand-dug ponds, dams, and trenches to harvest rainwater, which can be used for watering crops during the low rainfall season. Additionally, the study found that nine publications (13.6 %) mentioned irrigation schemes to adapt to climate change impacts. However, few countries reported using this strategy to increase the resilience of the farmers to climate change impacts (see Table 3).

Other strategies included agroforestry recognized (six studies; 9 %), inorganic fertilizers (five studies; 7.6 %), planting trees (eight studies; 12 %), and organic fertilizers (three studies; 4.5 %). Farmers used agroforestry and tree planting to reduce soil erosion, improve water catchment, and provide natural shade for their crops during extended dry periods. For example, rural farmers in Ghana intentionally leave big trees on their farms. Some studies also reported off-farm activities, such as seasonal migration (11 studies; 16.7 %), livelihood diversification (nine studies; 13.6 %), prayers (two studies; 3 %), and insurance schemes (two studies;3%; see Table 3).

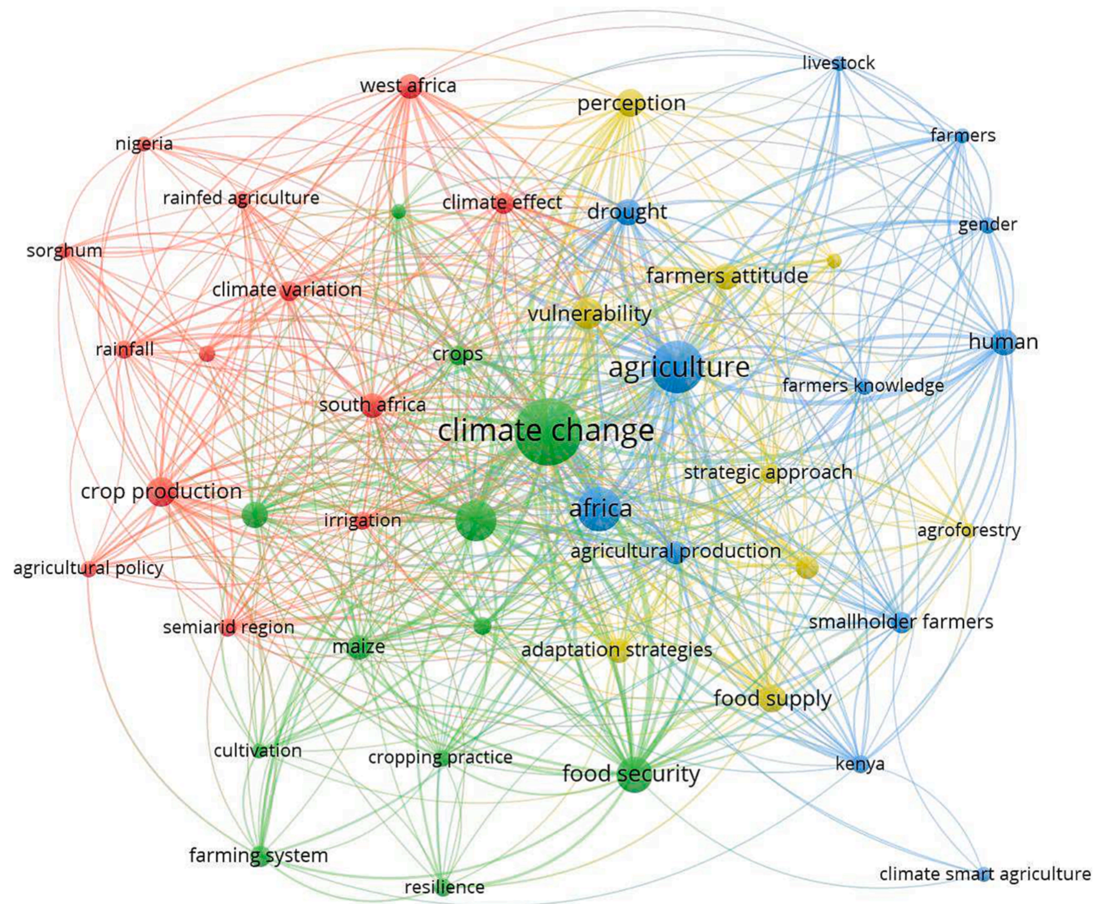

Fig. 4. Co-occurrence and interlinkages among keywords.

4. Discussion

This systematic review reveals a growing research interest in adaptation strategies used by farmers in Africa to climate change impacts. The study results present that the farmers are managing to adopt limited measures within their scope of capability. Implementing some of the researcher's recommended strategies like water management and access to new varieties, would be reasonable measures to cope with climate change. However, these strategies would need access and support from their respective countries' agricultural departments and funding institutions.

Sub-Saharan Africa appeared the most in studies reviewed compared with the Northern part of Africa. This finding might be associated with the region's high vulnerability to climate change impacts, attracting research attention (Ngcamu & Chari, 2020). Sub-Saharan Africa has been portrayed as the most vulnerable region globally due to its reliance on rain-fed agriculture and limited ability to mitigate such risks due to multiple stresses, such as endemic poverty, civil war and conflicts, poor technology, inadequate institutional capacities, and limited access to capital (Boko et al., 2007; Kotir, 2011; Ludi et al., 2012; Niang et al., 2014; Magesa & Pauline, 2019). The first relevant publication in 2001 could be linked with the publication of the third IPCC Assessment Report in 2001, which called for more investigations on adaptation measures undertaken by societies, especially in developing countries (McCarthy et al., 2001). This report might have encouraged researchers to start publishing on this topic. Other studies (e.g., Field et al., 2014a,b) show that the number of scientific publications on climate change adaptation, including farmers' adaptation strategies, has increased since 2005 in developing countries, including Africa. South Africa's domination of the number of research papers might be linked to South Africa having a large economy than other sub-Saharan countries, leading to more funds for research in academic and research institutions (Mouton et al., 2019). For example, in 2015, South Africa was ranked 44th worldwide and 1st in Africa in research funding (Mouton et al., 2019). Similar results were found in a study by Williams et al. (2018), which presented how the vulnerability of smallholder agricultural systems to climate change is being assessed in Africa, indicating that South Africa was also leading in the ranking with 40 %.

4.1. *Identification of principal adaptation strategies to climate variability and change in Africa*

4.1.1. *Crop varieties and management*

Climate change has led to several stress factors, such as increased heat, extreme weather events, droughts, poor soil fertility, high salinity, and increased crop diseases and pests, making the use of improved varieties of crops, such as heat, salt, and drought-tolerant and early-maturing varieties, necessary to increase the income and food security of smallholder farmers (World Bank, 2018). Stress-tolerant crops have increased resistance to climatic extremes in the region and play an essential role during harsh climatic conditions (Nagargade et al., 2017). These varieties are expected to increase productivity during the low rainfall season or high salinity levels. However, their viability is uncertain when extreme events, such as droughts, persist for a long time. Improved varieties of crops have been developed using innovative breeding techniques to increase the amount of genetic gain for multiple important traits of the seed sector (World Bank, 2018). Our review indicates that most African farmers use drought-tolerant and early maturing varieties, with a small number of disease-resistant varieties, to respond to climate change impacts. However, in some cases, using

Table 3
Identified Farmers' practising adaptation strategies to climate change in African countries.

Adaptation strategies	No of studies	% of studies	Country	Authors
Crop Varieties and Management				
Crop diversification	30	45	Uganda, Tanzania, Ethiopia, South Africa, Kenya, Niger, Burkina Faso, Benin, Zimbabwe, Ghana, Malawi, Senegal, Nigeria, Madagascar.	Atube et al., 2021; Paavola (2008); Bryan et al. (2009); Darabant et al., 2020; Kassie et al., 2013; Muroyiwa et al., 2021; Gbetibouo et al., 2010; Bryan et al. (2009); Myeni and Moeletsi (2020); Samuel and Sylvia, 2019a,b; Elum et al.(2018); Ngure et al., 2020; Waldman et al., 2019; Muita et al. (2015); McCord et al. (2015); Ado et al., 2020; Roncoli et al. (2001); West et al., 2008; Yegbemey, 2020; Yegbemey et al., 2017; Mavhura et al., 2015; Mashizha, 2019; Mupakati and Tanyanyiwa (2017); Osei, 2017; Antwi-Agyei et al. (2014); Amfo et al., 2020; Ngcamu and Chari, 2020; Abid, et al., 2019; Kotir (2011); Gandure et al. (2013); Mertz et al., 2009; Tarfa et al. (2019); Eludoyin et al., 2016; Harvey et al. (2014)
Planting drought-tolerant varieties	30	45	Uganda, Tanzania, Ethiopia, Ghana, Burkina Faso, Senegal, Mali, Kenya, South Africa, Zimbabwe, Ghana, Malawi, Nigeria, Eswatini, Madagascar,	Thomas et al., 2007; Bryan et al. (2009); Nindi and Mhando (2012); Antwi-Agyei et al. (2014); Harvey et al. (2014); Below et al., 2015; Fagariba et al., 2015; Mavhura et al., 2015; Traore et al. (2017) Elum et al.(2018); Mupakati and Tanyanyiwa (2017); Osei, 2017; García de Jalón et al., 2018; Popoola et al., 2018; Dube et al., 2018a; Dube et al., 2018b; Samuel and Sylvia, 2019a, b; Waldman et al., 2019; Bailey et al., 2019; Kogo et al., 2019; Abid, et al., 2019; Tarfa et al. (2019); Olajire et al., 2019; Frederick and Nielsen (2019); Darabant et al., 2020; Ngcamu and Chari, 2020; Alvar-Beltrán et al., 2020; Atube et al., 2021; Muroyiwa et al., 2021; Mburu et al., 2015; Nuamah and Amungwa (2021); Kativhu et al., 2020
Changing planting dates	28	42	Ethiopia, South Africa, Kenya, Niger, Mali, Burkina Faso, Benin, Ghana, Malawi, Nigeria, Togo, Cote d'Ivoire	Bryan et al. (2009); Darabant et al., 2020; Kassie et al., 2013; Talanow et al., 2021; Muroyiwa et al., 2021; Ndhleve et al. 2017; Gbetibouo et al., 2010; Bryan (2009b); Samuel and Sylvia, 2019a, b; Bryan et al., 2013; Kogo et al., 2019; Muita et al. (2015); McCord et al. (2015); Ado et al., 2020; Diallo et al., 2020; Traore et al. (2017); West et al., 2008; Baudoin et al., 2014; Fagariba et al., 2015; Antwi-Agyei et al. (2014); Daccache et al., 2015; Abid, et al., 2019; Kotir (2011); Popoola et al., 2018; Gandure *et al.* (2013); Olajire et al., 2019; Eludoyin *et al.*, 2016; Ali et al., 2020; Mburu et al., 2015); Mogomotsi et al., 2020; Comoe et al. (2014); Yegbemey, 2020; Nuamah and Amungwa (2021); Thinda et al., 2020
Planting early maturity crops	15	22.7	Tanzania, Ethiopia, Kenya, Botswana, Mali, Benin, Zimbabwe, Ghana, Nigeria, Cote d'Ivoire	Below et al., 2015; Darabant et al., 2020; Waldman et al., 2019; Kogo et al., 2019; Muita et al. (2015); Mogomotsi et al., 2020; Diallo et al., 2020; Traore et al. (2017); Baudoin et al., 2014; Ndlovu et al. (2020); Osei, 2017; Fagariba et al., 2015; Antwi-Agyei et al. (2014); Eludoyin *et al.*, 2016; Comoe et al. (2014); Mburu et al., 2015; Thinda et al., 2020
Use of Improved varieties	6	9	Ethiopia, Uganda, South Africa, Niger, Ghana,	Atube et al., 2021; Darabant et al., 2020; Thinda et al., 2020; Ado et al., 2020; Osei, 2017; Frederick and Nielsen (2019); Nuamah and Amungwa (2021); Thinda et al., 2020
Planting disease-resistant varieties	3	4.5	Ethiopia, Malawi, Nigeria	Darabant et al., 2020; Tarfa et al. (2019); Abid, et al., 2019
Use of flood-tolerant crop	1	1.5	Nigeria	Tarfa et al. (2019)
Planting trees	8	12	Uganda, Ethiopia, South Africa, Burkina Faso, Togo	Atube et al., 2021; Bryan et al. (2009); Darabant et al., 2020; Bryan (2009b); Alvar-Beltrán et al., 2020; Kotir (2011); Popoola et al., 2018; Ali *et al.*, 2020; Ado et al., 2020
Valley bottom cultivation	2	3	Burkina Faso, Tanzania	West et al., 2008; Nindi and Mhando (2012); Frederick and Nielsen (2019); Bryan et al., 2013; Thinda et al., 2020
Stream Bank Crop Cultivation	1	1.5	Zimbabwe	Dube et al., 2018a; Dube et al., 2018b
Cultivating crops in wetland areas and near water sources	1	1.5	Zimbabwe, South Africa	Popoola et al., 2018; Dube et al., 2018a; Dube et al., 2018b
Water and soil management				
Irrigation schemes	9	13.6	Ghana, Zimbabwe, South Africa, Nigeria, Tanzania, Ethiopia	Darabant et al., 2020; Muthelo et al., 2019; Thomas et al., 2007; Gbetibouo et al., 2010; Bryan (2009b); Williams et al., 2020; Williams et al., 2018; Olajire et al., 2019; Below et al., 2015; Ndhleve et al. 2017; Kativhu et al., 2020
Water harvesting dam, pond, and trenches	12	18.1	Tanzania, Kenya, Uganda, Ethiopia, Ghana, Burkina Faso, Senegal, Mali, Zimbabwe, Malawi, Nigeria, South Africa	Below et al., 2015; García de Jalón et al., 2018; Waldman et al., 2019; Kogo et al., 2019; Dube et al., 2018a; Dube et al., 2018b; Ndlovu et al. (2020b); Mupakati and Tanyanyiwa (2017); Osei, 2017; Williams et al., 2020; Daccache et al., 2015; Popoola et al., 2018; Olajire et al., 2019; Mburu et al., 2015; Yegbemey, 2020; Myeni and Moeletsi (2020)

(*continued on next page*)

Table 3 (*continued*)

Adaptation strategies	No of studies	% of studies	Country	Authors
Pump irrigation from the river	8	12	Ethiopia, South Africa, Ghana, Nigeria, Tanzania	Darabant et al., 2020; Muthelo et al., 2019; Thomas et al., 2007; Gbetibouo et al., 2010; Bryan (2009b); Williams et al., 2020; Williams et al., 2018; Olajire et al., 2019; Below et al., 2015
Boreholes and streams	7	10.6	South Africa, Malawi, Nigeria	Muthelo et al., 2019; Thomas et al., 2007; Gbetibouo et al., 2010; Osei, 2017; Daccache et al., 2015; Popoola et al., 2018; Olajire et al., 2019
Agroforestry	6	9	Tanzania, Kenya, Burkina Faso, Ghana	Below et al., 2015; Nindi and Mhando (2012); Quandt, 2020; Bryan et al., 2013; Alvar-Beltrán et al., 2020; Fagariba et al., 2015
Inorganic fertilizers	5	7.6	Ghana, Uganda	Mulinde et al. (2019); Ado et al., 2020; Williams et al., 2020; Williams et al., 2018; Kotir (2011); Nuamah and Amungwa (2021); Ali et al., 2020
Organic fertilizers	3	4.5	Tanzania, Mali, Nigeria	Below et al., 2015; Olajire et al., 2019; Diallo et al., 2020
Use of pesticide	2	3	Niger, Uganda	Ado et al., 2020; Mulinde et al. (2019)
Bucket irrigation from the river	1	1.5	Tanzania	Below et al., 2015
Deep tillage	1	1.5	Tanzania	Below et al., 2015
Financial schemes, Migration, Insurance, and Culture				
Livelihood diversification	9	13.6	Tanzania, Ethiopia, South Africa, Zimbabwe, Ghana, Senegal, Nigeria	Below et al., 2015; Darabant et al., 2020; Thinda et al., 2020; Mashizha, 2019; Antwi-Agyei et al. (2014); Kotir (2011); Mertz et al., 2009; Tarfa et al. (2019); Eludoyin et al., 2016; Ado et al., 2020; Mulinde et al. (2019); Nuamah and Amungwa (2021)
Seasonal migration	11	16.7	Tanzania, South Africa, Zimbabwe, Burkina Faso, Benin, Ghana, Senegal	Below et al., 2015; Nindi and Mhando (2012); Paavola (2008); Roncoli et al. (2001); West et al., 2008; Baudoin et al., 2014; Yegbemey et al., 2017; Ndlovu et al. (2020); Mashizha, 2019; Antwi-Agyei et al. (2014); Mertz et al., 2009; Thinda et al., 2020
Insurance schemes	2	3	South Africa	Muroyiwa et al., 2021; Muthelo et al., 2019; Nuamah and Amungwa (2021); Thinda et al., 2020
Prayers	2	3	Benin, South Africa,	Samuel and Sylvia, 2019a,b; Yegbemey et al., 2017; Comoe et al. (2014)
Credit schemes	7	10.6	Ghana, Tanzania, Malawi, Nigeria, Niger, Burkina Faso, Sub-Saharan Africa	Antwi-Agyei et al. (2014); Below et al., 2015; Abid, et al., 2019; Tarfa et al. (2019); Ado et al., 2020; Roncoli et al. (2001); Kotir (2011)
Agricultural and Weather Services				
Extension services	17	25.7	Madagascar, Tanzania, Ghana, Kenya, Malawi, Nigeria, Uganda, Kenya, South Africa, Benin, Ghana, Sub-Saharan Africa, Togo, Malawi, Zimbabwe	Harvey et al. (2014); Below et al., 2015; Osei, 2017; Kogo et al., 2019; Abid, et al., 2019; Tarfa et al. (2019); Atube et al., 2021; Mburu et al., 2015; Gbetibouo et al., 2010; Mulinde et al. (2019); Yegbemey, 2020; Nuamah and Amungwa (2021); Kotir (2011), Ali et al., 2020; Makate et al., 2019; Amadou et al., 2018
Early warning systems	1	1.5	Ghana	Antwi-Agyei et al. (2014)

improved varieties in the region was affected by their high prices, beyond the reach of farmers who lacked credit facilities.

Diversification is a risk management strategy that mixes various strategies to enrich the portfolio of economic activities and income gains (Kian et al., 2021). It involves a change in product choice and input use decisions based on profit maximization and market forces (Lakhran et al., 2017). Climate-Smart Agriculture (CSA)'s most important diversification strategies include crop and livelihood diversification (Makate et al., 2016; Kian et al., 2021). Crop diversification is a cropping system that involves adding new crops to agricultural production on a specific farm while considering the different returns from value-added crops corresponding to market opportunities (Makate et al., 2016). Crop diversification can minimize climatic and market risks while providing nutritious food at the household level (Lakhran et al., 2017). It also reduces the degradation of natural resources, as crop diversification can improve soil and water quality, food security, and carbon sequestration. The FAO (2017) found that crop diversification was the most common adaptation strategy adopted by farmers in Africa in response to climate change. Economic returns from crop diversification were highest among the poorest farmers. Similar results were found in this study, with crop diversification being the most used strategy by farmers in many African countries. Lipper et al. (2018) also found that poorer farmers in sub-Saharan Africa highly employed crop diversification and labour diversification.

4.1.2. *Water and soil management*

Irrigation and water management are considered important for crop production as climate change is expected to increase drought frequency, affect rains, raise average temperatures, and threaten freshwater resources for agricultural production on the continent (Alcadi et al., 2009). However, many African farmers use hand-dug ponds, dams, and trenches to harvest rainwater for watering crops during the dry season. This might be linked with the costs needed for building infrastructure systems for irrigation. Most of the agricultural production in the region is dominated by poor smallholder farmers in rural areas (Deressa et al., 2010; Pereira, 2017). Only 4 % of the area in production in sub-Saharan Africa and 5 % of the cultivated areas in Africa is under irrigation compared with 29 % in East Asia, 39 % in South Asia, and 14 % in Latin America (World Bank, 2007; Ringer et al., 2010; Kotir, 2011). Irrigation schemes established in some countries have inadequate technology, limiting their sustainability. For example, in the Gwanda district in Zimbabwe, there was a small irrigation scheme where a pump broke down and was unrepaired for a long time, leading to the collapse of the irrigation scheme (Dube et al., 2018a; Dube et al., 2018b). Irrigation is considered necessary for water management and as a soil management strategy. However, soil management strategies, including crop diversification, seem to be highly used by African farmers. Farmers are also using agroforestry and tree planting to reduce soil erosion, improve water catchment, and provide natural shade for crops during extended dry periods (Popoola et al., 2018; Atube et al., 2021).

4.1.3. *Environmental and natural resource management*

Environmental and natural resource management is among the essential aspects and features of CSA (Nagargade et al., 2017). CSA strategies should protect natural resources to enhance agroecosystem resilience and natural biological processes, reduce soil erosion, and

Table 4
Linkages between adaptation strategies and SDGs indicators (1: No poverty and 2: Zero hunger).

Adaptation Strategies	SDG Indicators (Appendix Table-1)	Positive and Negative Interactions
Crop Varieties and Management o Crop diversification Planting drought- tolerant varieties Changing planting dates Planting early maturity crops Use of Improved varieties Planting disease-resistant varieties Use of flood-tolerant crop	1.1.1, 1.2.1, 2.1.1, 2.1.2, 2.3.2	**Positive interactions (+)** These strategies can increase resistance to climatic extremes and productivity during low rainfall, leading to households' food security (SDG 2.1.1 & 2.1.2), increased income (SDG 2.3.2), and poverty reduction (SDG 1.1.1 & 1.2.1) (McCord et al. (2015; Ngcamu & Chari, 2020; Mburu et al., 2015) **Negative interactions (-)** Despite their importance, these strategies may provide limited additional benefits during times of severe decline in rainfall leading to food insecurity (SDG 2.1.1 & 2.1.2), a decrease in households' income (SDG 2.3.2), an increase in poverty (SDG 1.1.1 & 1.2.1) (Frederick & Nielsen (2019; Ngcamu & Chari, 2020; Mburu et al., 2015)
o Planting trees Valley bottom cultivation Stream Bank Crop Cultivation Cultivating crops in wetland areas and near water sources	1.1.1, 1.2.1, 2.1.1, 2.1.2, 2.3.2, 2.4.1	**Positive interactions (+)** These strategies can ensure continued agricultural productivity even during low rainfall seasons leading to increased food security (SDG 2.1.1 & 2.1.2), income (SDG 2.3.2), and poverty reduction (SDG 1.1.1 & 1.2.1) (Dube et al., 2018a; Dube et al., 2018b) **Negative interactions (-)** Cultivating in wetlands and near water sources, stream bank cultivation, and valley bottom cultivation can be a source of water pollution and drying of water resources, which can exacerbate the vulnerability of the natural and human systems as well as affect efforts to achieve sustainable agricultural practices (SDG 2.4.1)(Mburu et al., 2015; Dube et al., 2018a; Dube et al., 2018b; Popoola et al., 2018; Frederick & Nielsen, 2019)
Water management Irrigation schemes Water harvesting dam, pond, and trenches Pump irrigation from the river Boreholes and streams Bucket irrigation from the river	1.1.1. 1.2.1, 2.1.1, 2.1.2, 2.3.2, 2.4.1	**Positive Interactions (+)** Irrigation schemes lead to increased agricultural productivity even during severe droughts, leading to increased income for small-scale farmers (SDG 2.3.2), poverty reduction (SDG 1.1.1 & 1.2.1), and ensuring household food security (SDG 2.1.1 & 2.1.2). It is also a good soil and water management strategy contributing to sustainable agricultural practices (SDG 2.4.1) (Dube et al., 2018a; Dube et al., 2018b). **Negative Interactions (-)** Pump irrigation from rivers and streams may increase agricultural productivity even during low rainfall seasons, increasing households' food security, income, and poverty reduction. However, it is essential to note that these strategies require farm fields to be near the water sources (i.e., rivers or lakes), which may influence water pollution and sedimentation from agricultural activities, increasing the natural and human systems (Dube et al., 2018a; Dube et al., 2018b). This may affect the achievement of SDG indicator 2.4.1. Not only that, but also they may provide limited additional benefits during times of severe decline in rainfall leading to food insecurity and undernourishment (SDG 2.1.1 & 2.1.2) (Frederick & Nielsen, 2019).
Soil management o Agroforestry Inorganic fertilizers Organic fertilizers Deep tillage	1.1.1, 1.2.1, 2.1.1, 2.1.2, 2.3.2	**Positive interactions (+)** Organic fertilizers and agroforestry improve soil fertility, enhance system resilience to climate change, and maintain biodiversity on farmland (SDG 2.4.1); the patterns that increase agricultural productivity and households' income (SDG 2.3.2), food security (SDG 2.1.2), and poverty reduction (SDG 1.1.1 & 1.2.1) (Quandt, 2020). In addition, organic fertilizers and agroforestry reduces greenhouse gases and ensure sustainable farming practice (SDG 2.4.1) (Alvar-Beltrán et al., 2020) **Negative interactions (-)** Inorganic fertilizers may increase agriculture activity, which enhances households' food security and income. However, inorganic fertilizers lead to soil degradation, the patterns that may reduce crops production. In addition, inorganic fertilizers increase the emission of greenhouse gases hence affecting efforts to achieve sustainable agricultural practices (SDG 2.4.1) (Alvar-Beltrán et al., 2020)
Financial schemes, Migration, Insurance, and Culture o Livelihood diversification Seasonal migration Insurance schemes Prayers	1.1.1, 1.2.1, 2.1.1, 2.1.2, 2.3.2, 2.4.1	**Positive interactions (+)** These strategies can minimize climatic and market risks while providing nutritious food at the household level (SDG 2.1.1 & 2.1.2), leading to increased income (2.3.2), poverty reduction (SDG 1.1.1 & 1.2.1), and food security (Kristjanson et al., 2012; Ngure *et al.*, 2020). They can also improve soil and water quality (SDG 2.4.1) leading,to increased crops productivity. On the other hand, Insurance can buffer the financial implications of unintended crop failure following extreme events such as droughts and floods, leading to increased households' food security, income level, and poverty reduction. **Negative interactions (-)** Strategies (i.e., crop diversification) may provide limited additional benefits during times of severe decline in rainfall leading to food insecurity (SDG 2.1.1 & 2.3.2) (Frederick & Nielsen, 2019; Ngcamu & Chari, 2020), increase in poverty (SDG 1.1.1 & 1.2.1) and decrease in income (SDG 2.3.2). Not only that, but also there is no interaction between prayers and the aforementioned SDGs indicators.

provide other ecosystem services (Nagargade et al., 2017). Adaptation strategies should reduce environmental pollution, conserve natural resources, such as water, soil, and biodiversity, and increase the yield and income of smallholder farmers (Branca et al., 2012). Some of the adaptation strategies pursued by farmers in Africa may potentially threatens in surrounding areas (West et al., 2008; Nindi & Mhando, 2012). These strategies include stream bank cultivation in Zimbabwe (Dube et al., 2018a; Dube et al., 2018b), cultivating crops in wetland areas and near water sources in Zimbabwe and South Africa (Popoola et al., 2018; Dube et al., 2018a; Dube et al., 2018b), and valley bottom cultivation in Burkina Faso and Tanzania (West et al., 2008; Nindi & Mhando, 2012). All these strategies are practiced near water resources, contributing to sedimentation, pollution, and degradation. Agricultural practices such as water withdraw from rivers and streams for irrigation,

Table A1
Indicators for SDG 1 (No Poverty) and 2 (Zero hunger).

Indicators
1.1.1 Proportion of the population living below the international poverty line by sex, age, employment status, and geographic location (urban/rural)
1.2.1 Proportion of population living below the national poverty line, by sex and age.
2.1.1 Prevalence of undernourishment
2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)
2.3.2 Average income of small-scale food producers, by sex and indigenous status
2.4.1 Proportion of agricultural area under productive and sustainable agricultural practices
2.5.1 Number of plant and animal genetic resources for food and agriculture secured in either medium or long-term conservation facilities
2.5.2 Proportion of local breeds classified as being at risk of extinction

damming for water storage, excessive fertilizers use and vegetation clearing for crops production are cited to contribute to wetland loss which in turn affects important ecosystem services (i.e., flood regulation, climate regulation, soil erosion and infiltration of water) (Galbraith et al., 2005; Sinthumule & Netshisaulu, 2022).

4.1.4. Organic fertilizer amendment

Organic fertilizer amendment is considered an important strategy to reduce environmental impacts. It also has significant benefits, such as conserving soil fertility, improving system resilience to climate change, maintaining biodiversity on farmland, improving food security, and reducing greenhouse gases (Muller et al., 2016). It can modify soil's physical, chemical, and biological properties and enhance crop productivity (Badgley et al., 2007). Organic fertilizer amendment has a lower global warming potential than inorganic fertilizers (Larney & Angers, 2012). Additionally, 1.6 % of the nitrogen fertilizer applied in agriculture is emitted as nitrous oxide (Smith et al., 2007). Nitrous oxide emissions are projected to increase by 35 % to 60 % due to increased nitrogen fertilizer use by 2030 (Smith et al., 2007). Under these situations, organic fertilizer is becoming important to enhance crop production while reducing greenhouse gas emissions. It is also evident that green manure with diversified crop rotations diminishes nitrous oxide emissions and improves soil structure (Tuck et al., 2014). Additionally, soils managed organically have significantly lower mobile nitrogen concentrations and are more aerated (Badgley et al., 2007). This study indicated that farmers more often use inorganic fertilizers to improve soil fertility than organic fertilizers.

4.1.5. Reforestation, afforestation, and agroforestry

Reforestation refers to trees being returned or replanted in areas previously cleared (Le et al., 2011). In contrast, agroforestry refers to agricultural practices that incorporate food crop production or livestock with the cultivation of trees in the same field (Smith et al., 2007). Reforestation, afforestation and agroforestry enhance agroecological succession, maintaining the functionality and sustainability of farming systems. Additionally, forests play important roles in sequestrating carbon, maintaining ecosystem services, and improving social adaptation to climate change impacts (Le et al., 2011). We found that African farmers have used agroforestry (9 %) and tree planting (12 %).

4.1.6. Financial schemes, Migration, Insurance, and Culture

Livelihood diversification is another risk management strategy that involves a process through which rural families diversify a portfolio of social support capabilities and activities to survive and improve their living standards (Gautam & Andersen, 2016). More than 50 % of the income in rural farming societies in developing countries is from non-farm sources. Other studies have shown that diversification to non-farm livelihood strategies enables households to enhance food security and increase income and agricultural production by securing capital (e.g., Conway & Nwanze, 2010; Gautam & Andersen, 2016). It also helps them to cope with environmental stresses. Diversifying to off-farm activities requires a different level of investment to offer higher returns (FAO, 2017).

Furthermore, they demand higher investment in terms of social,

Table A2
Journal-wise distribution of selected studies.

S/N	Journal /or book name in which a paper was published	Book	Journal	No. of publications
1	Climate change		✓	5
2	Environmental management		✓	4
3	Jamba: Journal of disaster risk studies		✓	3
4	Environment development and sustainability		✓	3
5	Environmental science and policy		✓	2
6	Climate and development		✓	2
7	Sustainability		✓	2
8	GeoJournal		✓	2
9	Cogent social sciences		✓	2
10	International journal of environmental research and public health		✓	2
11	Climate risk management		✓	2
12	Land use policy		✓	2
13	Mitigation and adaptation strategies for global change		✓	2
14	Journal of human ecology		✓	1
15	Climate change and the sustainable use of water resources	✓		1
16	West African journal of applied ecology		✓	1
17	Philosophical transactions of the royal society		✓	1
18	Regional environmental change		✓	1
19	Fields of crops research		✓	1
20	Journal of water and climate change		✓	1
21	Applied ecology and environmental research		✓	1
22	Agricultural research		✓	1
23	AMBIO		✓	1
24	Atmosphere		✓	1
25	African Journal of science, technology, innovation, and development		✓	1
26	Agriculture and food security		✓	1
27	Journal of rural studies		✓	1
28	Water SA		✓	1
29	Agrekon		✓	1
30	Wiley interdisciplinary reviews-water		✓	1
31	International journal of agricultural sustainability		✓	1
32	Water		✓	1
33	NJAS-Wageningen journal of life sciences		✓	1
34	Agroforestry systems		✓	1
35	Outlook on agriculture		✓	1
36	Business strategy and development		✓	1
37	African handbook of climate change adaptation	✓		1
38	Climate research		✓	1
39	Environmental development		✓	1
40	American meteorological society		✓	1
41	Cogent food and agriculture		✓	1
42	Agriculture- Basel		✓	1
43	African journal of food, agriculture, nutrition and development		✓	1
44	Forest policy and economics		✓	1
45	Water practice and technology		✓	1
46	Agricultural systems		✓	1
TOTAL				**66**

human, and financial capital to start up, making poor households less likely to be involved in high-return sectors, and diversification may not substantially help smallholder farmers get out of poverty (Gautam & Andersen, 2016; FAO, 2017). Additionally, crop insurance plays a vital role in adaptation to climate change impacts (Di Falco et al., 2013). It can buffer the financial implications of unintended crop failure following extreme events like droughts and floods.

Migration has also been recognized as an important way to diversify agricultural-based livelihoods, particularly in sub-Saharan Africa (Tacoli, 2011a). Migration allows individuals to diversify their income and send remittances back to family members. It enables risks to be spread in households, increasing resilience back home (Tacoli, 2011b). Additionally, migration can be a successful adaptation strategy in terms of labour mobility, helping family members back home through remittances to meet their basic needs, such as food in times of livelihood shocks, and financing the acquisition of social, human, physical, and natural capital (Barnett and O'Neill, 2010). However, migration is often only an option available for the privileged. Those populations or families with no financial or social capital to move can be left *in situ* in risky situations (Ober, 2014). Given such circumstances, in situ interventions to increase the resilience of this group should be considered to offer diverse livelihood options.

4.2. Diffusion of climate Smart agriculture (CSA) adaptation strategies

Climate Smart Agriculture has emerged as an approach that intends to transform the agricultural system to enhance food production while dealing with the impacts and increasing variability of climatic change (Abegunde et al., 2019). CSA has three main goals: sustainably increasing agricultural productivity to enhance food security, income levels, and development; enhancing climate change adaptation and resilience from farm to national levels; and developing opportunities to reduce the emission of greenhouse gases from agriculture (Branca et al., 2012). It has become important to identify the most suitable adaptation strategies according to local and national priorities and conditions to meet these three objectives (Abegunde et al., 2019). With the current SDGs, the world is committing to ending hunger, improving nutrition and food security, and promoting sustainable agriculture (SDG 2) while also ensuring poverty reduction (SDG 1). Therefore, it is vital to assess the concept of CSA among smallholder farmers and consider its feasibility in achieving food security and poverty alleviation (Abegunde et al., 2019).

4.3. Adaptation strategies and their potential contributions towards SDGs 1 and 2

As already mentioned, Africa is the poorest and most food-insecure region globally (Kotir, 2011), making SDGs 1 and 2 the most critical goals in Africa. Several studies (e.g., Dinar et al., 2008; Kotir, 2011) indicate that the current impacts of climate change in the region are already severe and technological change has been slow, particularly in the sub-Saharan region. Agricultural productivity has declined over the last 50 years (Ward et al., 2013; Kotir, 2011). The highest prevalence of undernourishment has been observed in the region despite the adaptation strategies used by farmers to lessen the impacts of climate change on agricultural production in Africa (Ward et al., 2013). For example (Harvey et al., 2014), using household surveys in Madagascar, found that, although farmers employed various adaptation strategies to tackle climate change (e.g., planting new crop varieties, crop diversification, and drought-tolerant crops), these strategies were still insufficient to prevent them from remaining food insecure. Mavhura et al. (2015) found that numerous farmers' adaptation strategies, including drought-tolerant crops, short-season cultivars, and crop variety diversification, were used to cope with drought events in the Zambezi Valley in Zimbabwe, have been ineffective in reducing the impact of drought on food security.

Additionally, (Nuamah & Amungwa 2021) found that most adaptation strategies used by smallholder farmers did not necessarily enhance livelihood and food security. Further, Frederick and Nielsen (2019) used household surveys, FGDs, and semi-structured interviews in Lawra District in Ghana to show that climate change extremes (e.g., droughts) challenge several adaptation strategies (e.g., improved crop varieties, use of fertilizers and pesticides) used by smallholder farmers, causing a decline in crop yield leading to financial debt. Studies from Ghana (Frederick & Nielsen, 2019) and Ethiopia (Darabant et al., 2020) show that despite adaptation strategies such as improved crop varieties to withstand climate variability and change, they might not be effective during times of extreme climate events. During participant interviews, Frederick & Nielsen (2019) noted that returning better yields during droughts is still challenging despite using fertilizers and pesticides as adaptation strategies. These strategies (e.g., improved crop varieties, fertilizers, and pesticides) work better in wet soils. Therefore, a shortage of adequate rainfall has challenged these adaptation strategies leading to crop failure. Using household surveys, Bailey et al. (2019) found that adaptation strategies such as planting drought-tolerant crops and conservation farming by smallholder farmers in Lubombo District in Eswatini did not improve the nutritional status of children in most households due to drought severity from 2015 to 2016 throughout the country. Furthermore, Popoola et al. (2018) used household surveys in the Amathole District in South Africa to reveal that adaptation strategies adopted by smallholder farmers (i.e., changing planting dates, cultivating crops near water sources, growing crops in wetlands) were insufficient to combat the impacts of climate change in the region.

Additionally, people living in poverty increased from 278 million in 1990 to 413 million in 2015 (Beegle & Christiaensen, 2019). These trends indicate that without proper adaptation planning and investments, SDG indicators, such as reducing the proportion of the population living below international and national poverty lines (Indicator 1.1.1 & 1.2.1), reducing undernourishment (2.1.1), reducing moderate or severe food insecurity (2.1.2), and increasing the average income of small-scale producers (2.3.2), will be challenging to achieve in the region (see Table 4).

Humans have been adapting to climate change throughout history, but the current impacts of climate change are very rapid and unprecedented in human history, requiring new ways of doing things (Magesa & Pauline, 2019). Transformative adaptations are required when vulnerability and climate change impacts are particularly extreme and rapid (Field et al., 2012; Magesa & Pauline, 2019). It also requires fundamental changes to the nature of a system once current social, economic, and ecological conditions become undesirable (Magesa & Pauline, 2019). Kates et al. (2012) added that transformative adaptations are genuinely new to a particular region and capable of transforming the place and shifting locations. They include actions that increase society's resilience by changing fundamental attributes of a system in response to climate change impacts (Hug et al., 2014). In contrast, incremental adaptations include actions that minimize the adverse effects of climate change with a central focus on maintaining the essence and integrity of existing technological systems, value systems, institutional capacity, and governance (Field et al., 2014a,b). They seek to preserve the existing system's efficiency and operate within the status quo (Magesa & Pauline, 2019).

It is widely agreed that assessing the positive and negative interactions between farmers' adaptation strategies to help policymakers and researchers to understand the developmental pathways that enhance positive interactions and minimize the negative ones is essential. For example, as shown in Table 4, crop diversification, planting drought-tolerant varieties, changing planting dates, and using early-maturity crops are welcome and may be beneficial in responding to climate change impacts. However, they might not be effective during times of more extreme climate changes in the coming decades (Harvey et al., 2014; Trisos et al., 2022). For example, crop diversifications, changing planting dates, planting drought-tolerant varieties, and planting early-maturity crops, can allow continued production, even with substantial rainfall reductions. Still, they provide limited additional benefits during times of more severe declines in rainfall (Howden et al., 2010) (see Table 4). Hence, it is vital to consider supplementary strategies such as irrigation facilities to help farmers during severe droughts. Therefore, achieving SDG 1 will be difficult for most African farmers. With the current climate change impacts and some evidence from the region (e.g., increasing endemic poverty and food insecurity), we believe that achieving SDGs 1 and 2 will be unlikely without transformational adaptation in the African agricultural system. Kristjanson et al. (2012) used household surveys in Tanzania, Kenya, Ethiopia, and Uganda to show that many farming households employed marginal rather than transformational adaptation strategies. Conversely, Niang et al. (2014) and Frederick & Nielsen (2019) added that most adaptation strategies used by farmers in sub-Saharan Africa to climate variability and change are reactive to short-term motivation, are incremental, occur at the household level, and lack support from government stakeholders. Additionally, (Williams et al., 2021; Trisos et al., 2022) indicated that about 83 % of adaptation strategies assessed in Africa, including those used by farmers, showed medium potential for risk reduction. Trisos et al. (2022) further indicated that adaptation strategies, such as adjusting planting times, may reach their adaptation limit above 1.5 °C and 2.5 °C global warming.

We suggest that achieving SDGs in Africa requires more transformative changes, such as increasing crop insurance schemes for farmers, expanding irrigation schemes, using improved varieties, and increasing opportunities for livelihood diversification. These should be considered in addition to the currently employed adaptations. Other measures needed to transform African agriculture toward achieving the mentioned SDG goals include increased access to credit facilities, improved access to markets for selling crops, capacity building of farmers on sustainable practices, such as CSA, improved rural transportation infrastructure, and storage facilities and increased farmer access to extension services.

4.4. Limitations and future research of the study

The limitation of this study was conducting literature searches using only the English language without considering other languages, such as French and Arabic, which are dominant in North Africa. The study did not use the grey literature from the Google Scholar database for literature searches since the study focused only on the peer-reviewed journals from Scopus and Web of Science which could also be a limitation of this paper. Future research should focus on adaptation strategies and investigate farmers' willingness and difficulties to accept new adaptation strategies and their significant factors. Further, explore how these adaptation strategies potentially contribute toward achieving SDGs 1 and 2 and assess the tradeoff and synergies among other relevant SDGs at the agricultural household level.

5. Conclusions

This study offers a practical examination of the efficiency of farmers' adaptation strategies to climate change in Africa. In addition, the review reports systematically that several studies have focused more on farmers' implemented adaptation strategies than researchers' recommended strategies. The adaptation measures already implemented by the farmers help cope with climate change in Africa's agricultural system. Adaptation strategies (i.e., crop diversification, planting drought tolerant varieties, changing planting dates; and planting early maturity crops) are a welcome development and may be beneficial for responding to the impacts of climate change. However, they might not be effective during times of more extreme climate changes and at higher global warming levels in the coming decades. An important observation identified in our study was to investigate the role of causal factors for the improvement and adoption of new and modified measures recommended by the researchers and extension officers apart from farmers' existing strategies. Nevertheless, the rate of farmers' adoption of these strategies is limited. For instance, recommended strategies such as planting early maturity crops appeared in 15 (22.5 %) studies, the use of improved varieties in 6 (9 %), irrigation schemes in 9 (13.6 %), and livelihood diversification in 9 (13.6) studies. Other important recommended strategies, such as credit schemes, appeared in 7 (10.6 %), and insurance schemes exhibited 2 (3 %). Farmers might be willing to adopt recommended strategies but are hindered by higher costs for farm inputs and access to irrigation technology. A limited number of irrigation systems are underdeveloped and rely on using hand-dug ponds, dams, and trenches to harvest rainwater for watering crops during the dry season.

Livelihood diversification and seasonal migration strategies are notified as an alternative adaptation measure for the farmers to support their families during prolonged droughts and low farm productivity.

Based on these study findings supporting transformational changes in addition to the currently employed adaptation strategies is needed (Mavhura et al., 2015). Strengthening appropriate stakeholders, including central governments, local government authorities, non-government organizations, and other development practitioners, helps build more infrastructure for irrigation systems, promote crop insurance and improved varieties, and increase opportunities for livelihood diversification (Popoola et al., 2018). Lastly, the positive and negative interactions between adaptation strategies play an effective tool in assessing the potential contribution towards no poverty and zero hunger goals.

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CRediT authorship contribution statement

Bahati A. Magesa: Conceptualization, Methodology, Writing – original draft. **Geetha Mohan:** Supervision, Conceptualization, Writing – review & editing. **Hirotaka Matsuda:** Writing – review & editing. **Indrek Melts:** Writing – review & editing. **Mohamed Kefi:** Writing – review & editing. **Kensuke Fukushi:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix 1

Appendix 2

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